MODEL STUDIES OF APRA HARBOR, GUAM, M.I.

PROGRESS REPORT for MAY, 1948

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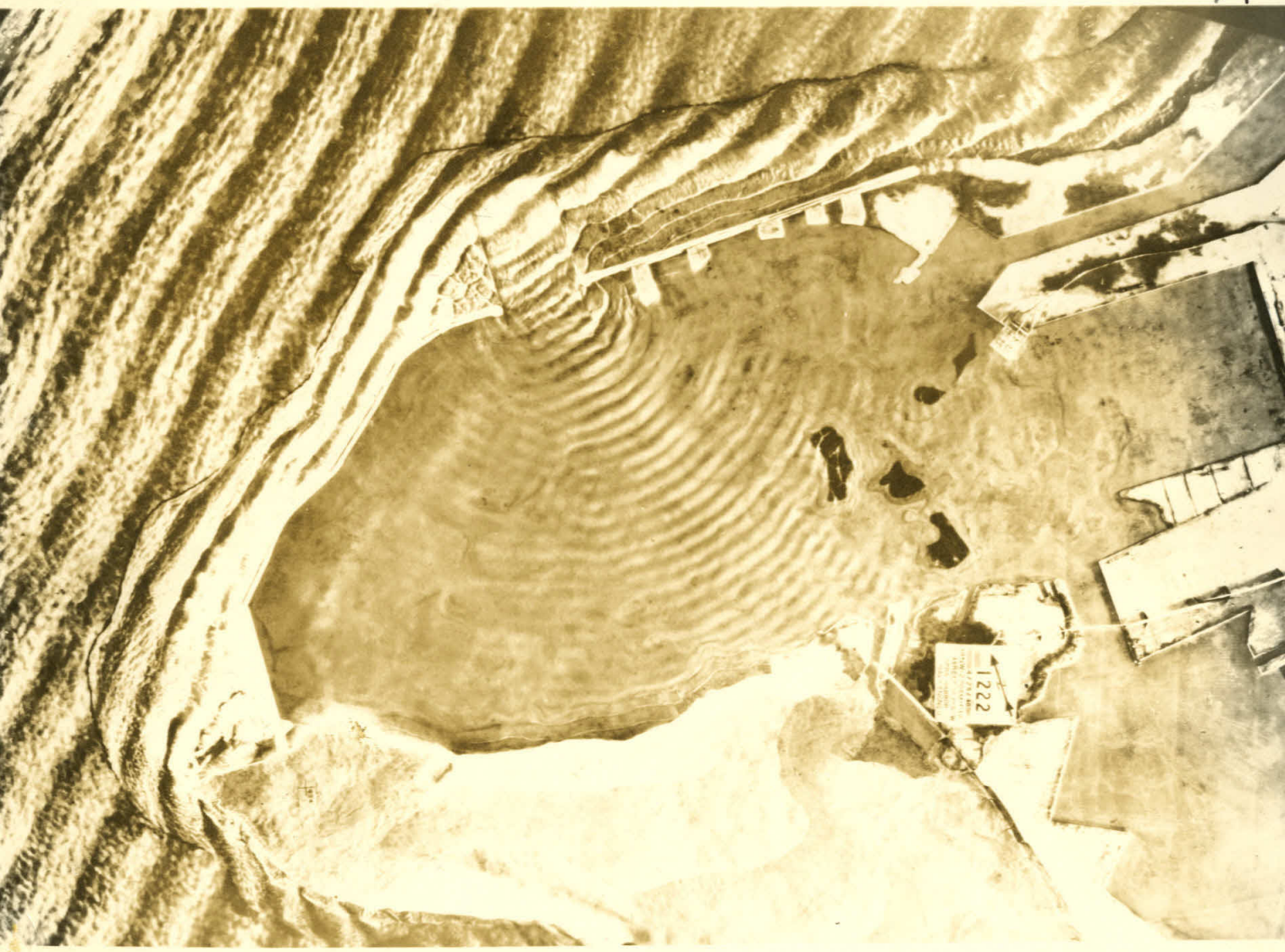

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CALIFORNIA INSTITUTE OF TECHNOLOGY
Hydrodynamics Laboratories, Hydraulic Structures Division

Operating Under
Contract NOy-12561 United States Navy Department

Contract NOy-12561
U. S. NAVY DEPARTMENT
BUREAU OF YARDS AND DOCKS

MODEL STUDIES
of
APRA HARBOR, GUAM, M.I.

PROGRESS REPORT
for
MAY 1948

HYDRODYNAMICS LABORATORIES
HYDRAULIC STRUCTURES DIVISION
of the
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena 4, California

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June 1, 1948

On the cover are shown northwesterly waves, 30 feet high, 1200 feet long, passing through the Luminao Reef entrance into the harbor. The advantage of this entrance, O-4, in permitting the wave fronts to spread over a large width is well illustrated.

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I INTRODUCTION

Tests of three different inner breakwaters to protect the repair basin and inner harbor from waves entering through the existing harbor entrance were run this month. Two were located on Jade and Southern Shoals and one on Jade, Southern and Western Shoals. The breakwaters on the shoals reduce the disturbances in the areas of primary and secondary usage in the repair basin to less than half those occurring with the shoals alone. Combinations of breakwaters and channel fills between the various shoals supplemented the studies and these results are included as well.

Tests were also run to compare the effectiveness in the outer harbor of the alternate entrance through Luminao Reef with that of the existing entrance between Spanish Rocks and Orote Point. The alternate entrance is very effective.

In addition to the tests described above, induced current studies were made. Many of these were for the purpose of developing the technique of daytime photography of reflector floats. Because test runs at the end of the month are incomplete and do not comprise a logical unit for presentation, their analysis will appear in next month's report.

Visitors included a group of 138 members and guests of the Los Angeles chapter of the American Society of Civil Engineers and a group of 30 organized Navy reserve officers from Pasadena.

II SCOPE OF THIS REPORT

Two distinct series of tests were completed during the month. One embodied runs to compare the effectiveness of each of three different breakwater structures located on the tops of Jade, Southern, and Western Shoals. Combinations of channel fills were also studied and are presented as a part of this section. This series of tests was made with the harbor entrance as it presently exists. The four ocean conditions used in the tests were westerly waves 30 feet high, 600 feet and 1200 feet long, each at MHHW.

The second series of tests embodied a quantitative comparison of the relative effectiveness in the outer harbor of an alternate entrance through Luminao Reef versus the existing entrance. Four stations were selected to represent typical areas in the outer harbor and wave height measurements were made at these stations under the various applicable ocean conditions for each of the two entrances under consideration. The ocean conditions were those involving waves 30 feet high, 600 and 1200 feet long from the west, from the northwest, and from the north at MHHW. The analysis of the measurements in the outer harbor have been combined with a rearrangement of the data given last month for the repair basin and inner harbor in order to present a more comprehensive comparison of the reef entrance (O-4) with the existing entrance.

III TESTS OF INNER BREAKWATERS ON JADE, SOUTHERN AND WESTERN SHOALS

Discussion

Some time ago considerable attention was given to inner breakwater alignments under the proposals set forth in Harbor Development Plan #1. Numerous inner breakwater alignments were tested under this plan. When Harbor Development Plan #2 was presented to the laboratory for study the two plans were found to be considerably different. It was immediately seen that the disturbances in the repair basin areas would not be the same for the two plans. Accordingly the breakwater alignments already studied could only be used as a guide for Plan #2.

Because stress was placed on the importance of first determining the effectiveness of the reefs in quelling disturbances in the repair basin and inner harbor under Plan #2, tests on inner breakwaters were temporarily halted. During the past month inner breakwater tests were resumed. Their results are included in this report.

Three alignments were studied, all differing somewhat from those under Plan #1. Underwater topography from dredging reports received a few months ago did not agree with the topography shown on earlier charts from which the model was constructed. Requests were therefore made by the laboratory for topographic field checks in critical areas in the vicinity of Jade and Southern Shoals. These checks revealed that the topography was in many instances radically different from that originally used. The breakwater alignments previously studied were no longer practicable because they would extend into water over 100 feet deep in places. The new alignments have been selected to fit the topography as it is now known and to approximate as well as possible the old alignments

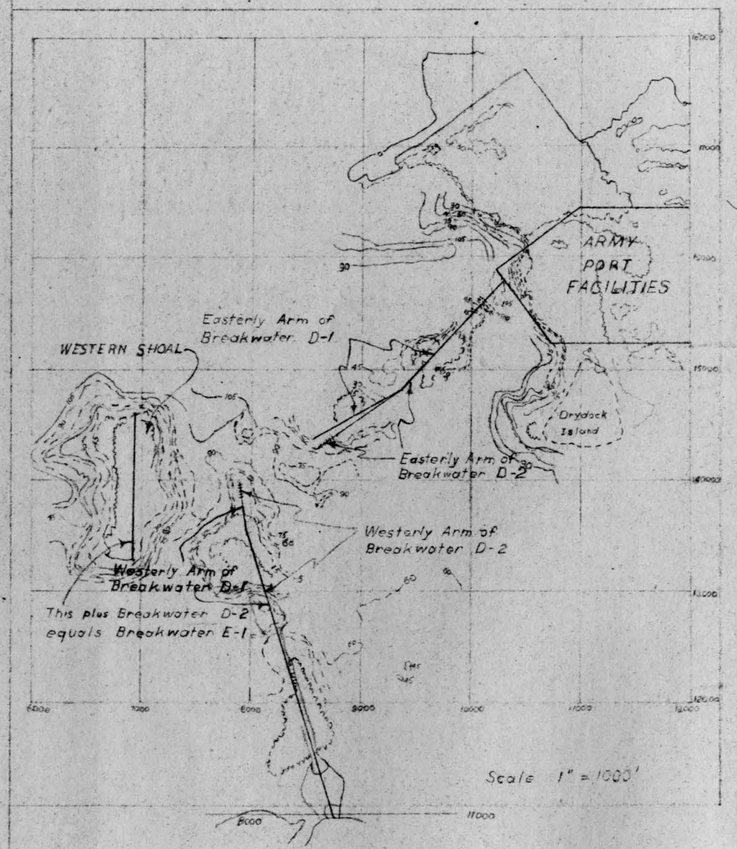
to take advantage of their best features. The three new alignments, described below, are shown on Plate 1.

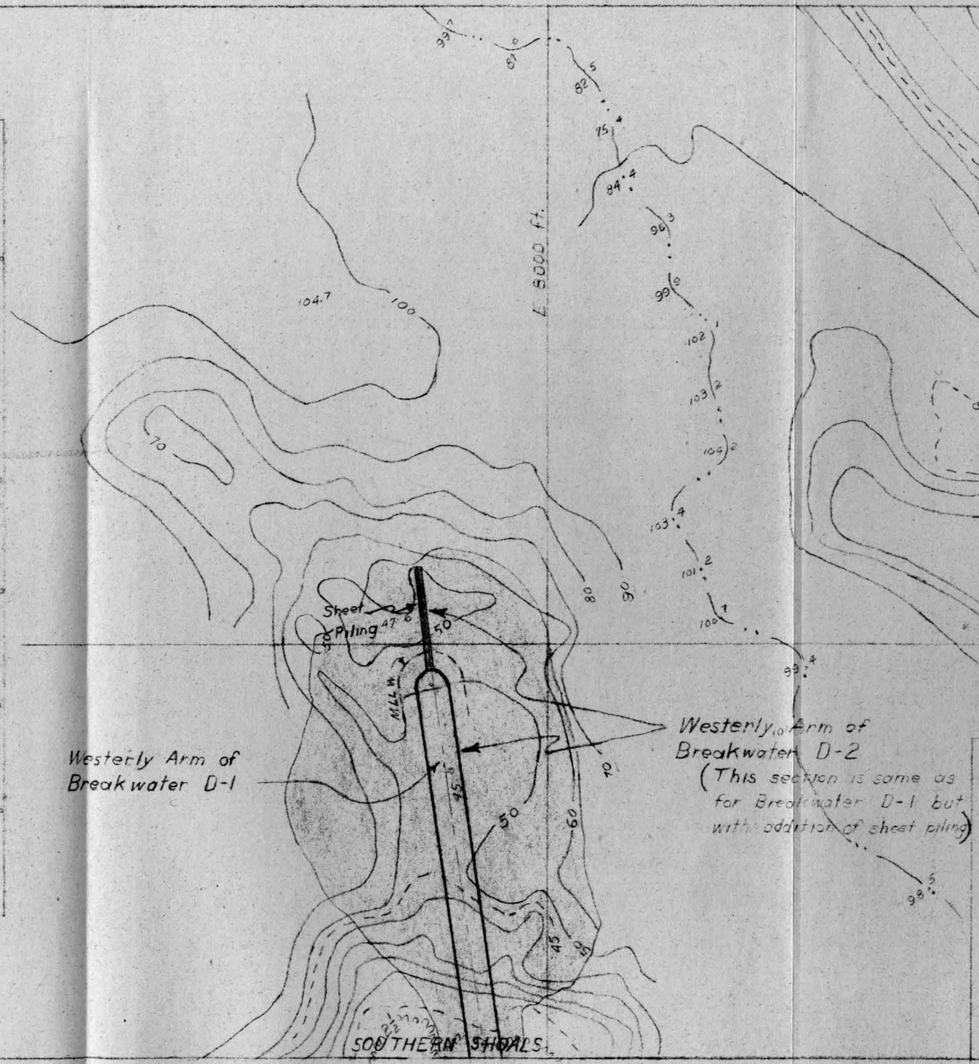
D-1: A rock breakwater on Jade and Southern Shoals, extending northerly on Southern Shoals to a point such that the toe of the fill ($1\frac{1}{2}$ on 1 slope) is at approximately -50 feet from MLLW, and extending southwesterly on Jade Shoals to a similar point. The total opening is 740 feet and the component of this opening parallel to the incoming wave front is 380 feet.

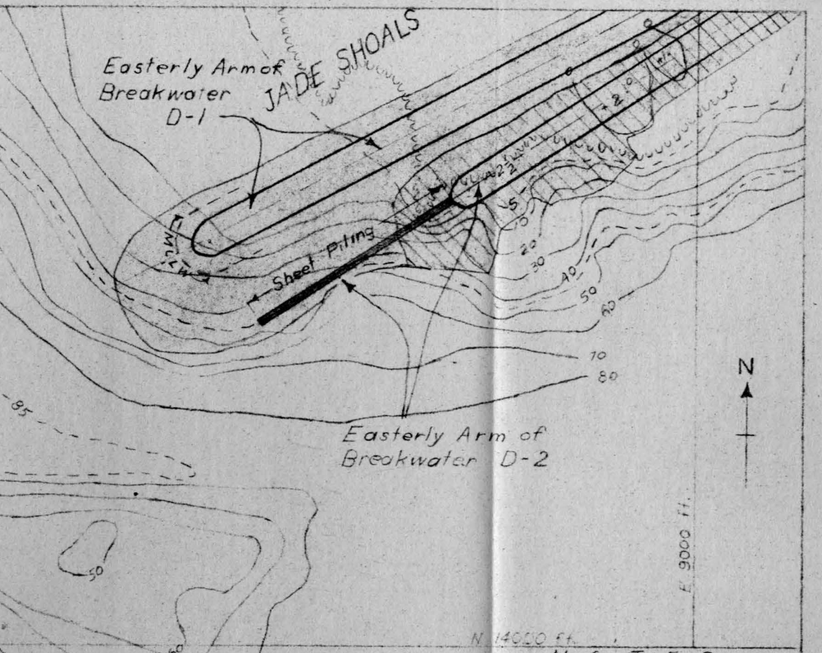
D-2: Similar to D-1 breakwater except for the use of sheet piling at the end of each arm. The sheet piling goes out to depths of 45 feet and in effect gives added length to the breakwater, unattainable with fill alone because of the depths that would otherwise be encountered. The arm on the southwesterly Jade Shoal is swung farther to the south than with D-1 to take advantage of the topography and thereby decrease the opening parallel to the incoming wave front. The total opening is 770 feet, with a component parallel to the incoming wave front of only 220 feet.

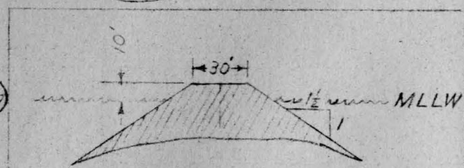
E-1: The same as D-2, but with the addition of a breakwater segment on Western Shoal.

In addition to studies of these basic alignments, combinations of channel fills were also considered and tested for breakwaters D-1 and D-2. These have been designated as D-1a, b and c and D-2a, b and c and can be seen in the sketch on the following page. The "a" indicates the









TYPICAL BREAKWATER CROSS SECTION
Scale 1" = 60'

NOTES

1. All contours are in feet below MLLW unless otherwise noted.
2. Data is from Drwg's "SC-26 & SC-78 dated Feb. & March 48 of GUAM DREDGING CONTRACTORS. These show soundings in feet.
3. Grid shown is harbor grid established by Guam Dredging Company.

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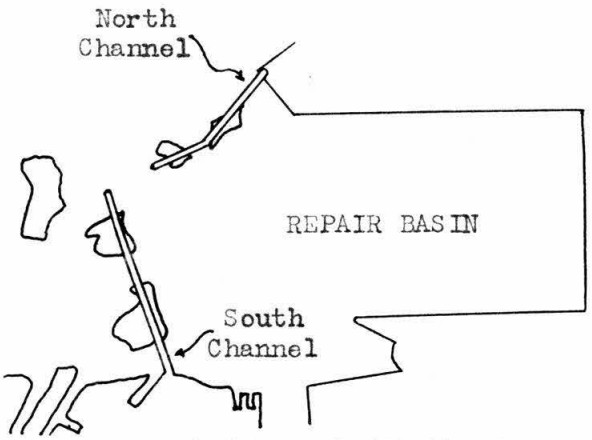
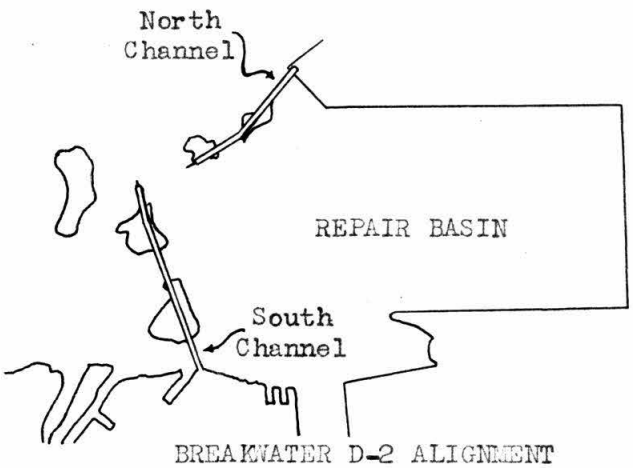
ALIGNMENTS OF BREAKWATERS D-1, D-2, AND E-1

DR	OMM. 6/3/48	SCALE 1" = 100'
CH	6/4/48	
AP	6/5/48	1093

PLATE I



BREAKWATER D-1 ALIGNMENT



BREAKWATER D-2 ALIGNMENT

omission of the fill across the "North Channel", i.e. the channel between Army Port Facilities and Jade Shoals. The "b" indicates the omission of the fills across both the "North" and "South Channel" (the channel between Southern Shoals and the south shore of the harbor). The "c" indicates the omission of the fill across the "South Channel" only.

The same eight wave height measuring stations previously selected were used to represent typical areas in the repair basin and inner harbor. These eight stations and the areas they represent are:

a. Areas of primary usage - repair basin

Wave Height Measuring Station # 6 - at the carrier base
#14 - center of north shore
#20 - center of south shore
#22 - "I-J" Docks

b. Areas of secondary usage - along east shore of repair basin

Wave Height Measuring Station #16 - north half east shore
#18 - south half east shore

c. Areas of specific usage

1. Southwest end of Army Port Facilities

Station #12

2. Entrance to inner harbor

Station # 3

In the lower left hand corner of Plates 2, 3, and 4 the locations of each of these array stations may be seen.

Table I presents quantitative ratings of the three inner breakwaters and their modifications as determined by wave height measurements in the areas of primary and secondary usage in the repair basin, (a) and (b) above. The disturbances at the four stations listed under (a) are averaged arithmetically to obtain a figure representative of the areas of primary usage. Similarly, the disturbances at the two stations listed under (b) are averaged arithmetically to obtain a figure representative of the areas of secondary usage. Comparisons have not been made at the southwest end of Army Port Facilities because of the erratic performance in this region and the consequent meaningless results. Because the disturbances at the entrance to the inner harbor are small and of approximately equal magnitude no comparisons have been made for this station either.

Plate 2 presents a detailed comparison of the effectiveness of the three basic breakwaters with that of the shoals alone. Except with waves 600 feet long at stations 20 and 22, (I-J Docks and along the south shore of the repair basin), the disturbances are all greatly reduced by the breakwaters. The reduction with 1200 feet long waves is much more noticeable than with 600 feet long waves.

A detailed comparison of the four variations of breakwater D-1 are shown on Plate 3 and of the four variations of breakwater D-2 on Plate 4. Generally, either the North or South Channel may be left open without ill effects, but not both.

TABLE 1

Quantitative Ratings of Inner Breakwaters
built on
Jade, Southern and Western Shoals
as determined by
Maximum Wave Height Measurements
Under Selected Ocean Conditions at MHHW

Structure	Max. Disturbances in Percent of Imposed Wave Height			Disturbance Compared to that occurring with Shoals JSW alone (in percent)
	600 ft. long waves	1200 ft. long waves	Ave.	
Areas of Primary Usage				
Shoals JSW	5.4	10.2	7.8	100
Breakwater D-1	5.0	2.0	3.5	45
" D-1a	4.8	2.6	3.7	48
" D-1b	6.0	3.3	4.7	60
" D-1c	6.4	2.2	4.3	55
" D-2	5.7	2.6	4.2	54
" D-2a	4.4	2.7	3.6	46
" D-2b	3.7	4.4	4.1	53
" D-2c	3.1	3.2	3.2	41
" E-1	4.7	2.3	3.5	45
Areas of Secondary Usage				
Shoals JSW	7.6	9.1	8.4	100
Breakwater D-1	3.7	2.4	3.1	37
" D-1a	4.4	2.8	3.6	43
" D-1b	4.4	2.9	3.7	44
" D-1c	4.5	2.4	3.4	40
" D-2	4.4	2.5	3.4	40
" D-2a	4.9	2.0	3.5	42
" D-2b	3.2	3.9	3.6	43
" D-2c	4.9	2.4	3.6	43
" E-1	3.7	2.8	3.2	38

COMPARATIVE EFFECTIVENESS OF
SHOALS JSW AND THREE INNER BREAKWATERS
AS MEASURED BY MAXIMUM DISTURBANCES IN REPAIR BASIN AND VICINITY
30 FEET HIGH WESTERLY WAVES AT MHHW

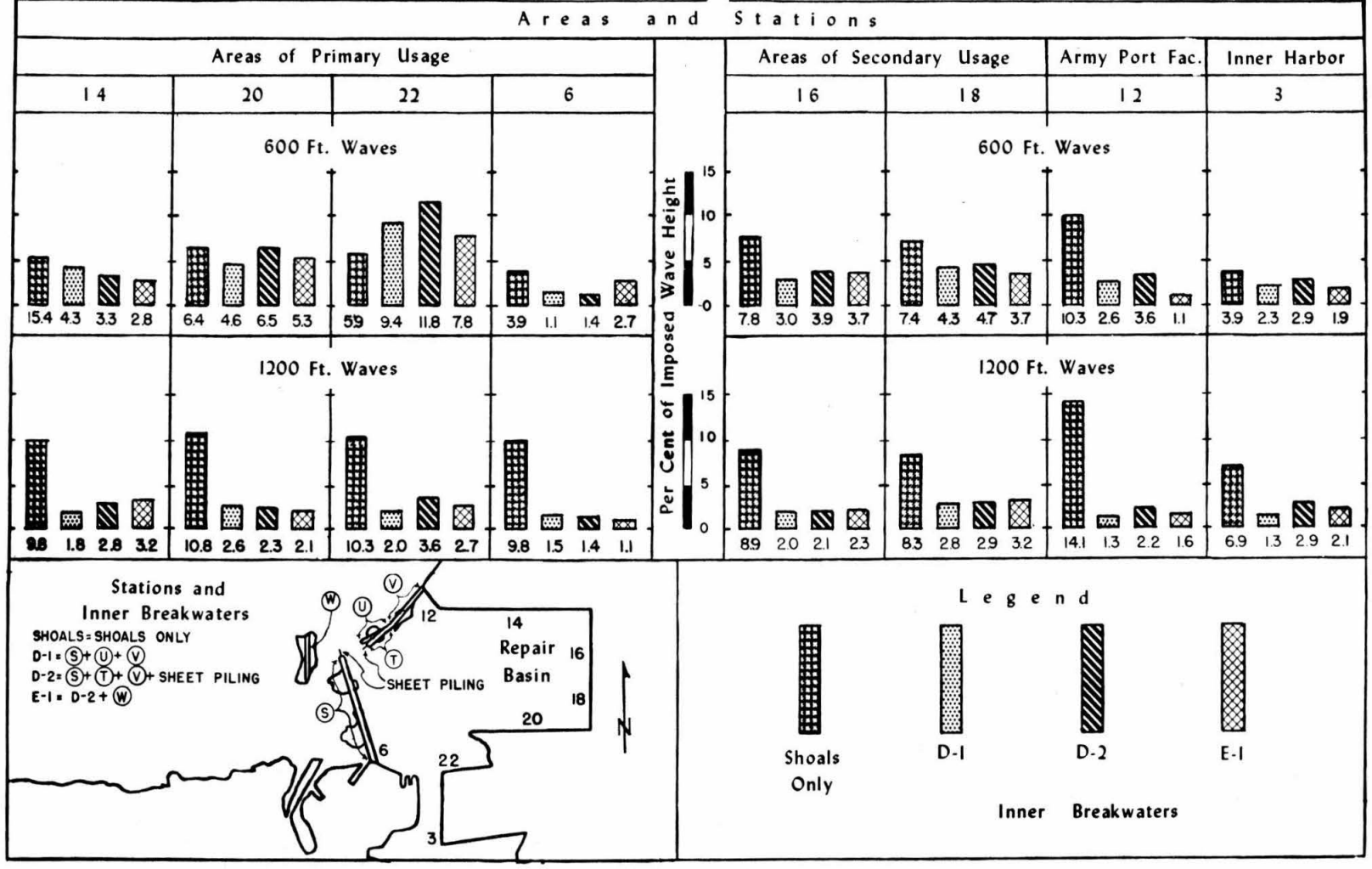


Plate 2

COMPARATIVE EFFECTS OF

MODIFICATIONS OF BREAKWATER D-1

AS MEASURED BY MAXIMUM DISTURBANCES IN REPAIR BASIN AND VICINITY

30 FEET HIGH **WESTERLY** WAVES AT MHHW

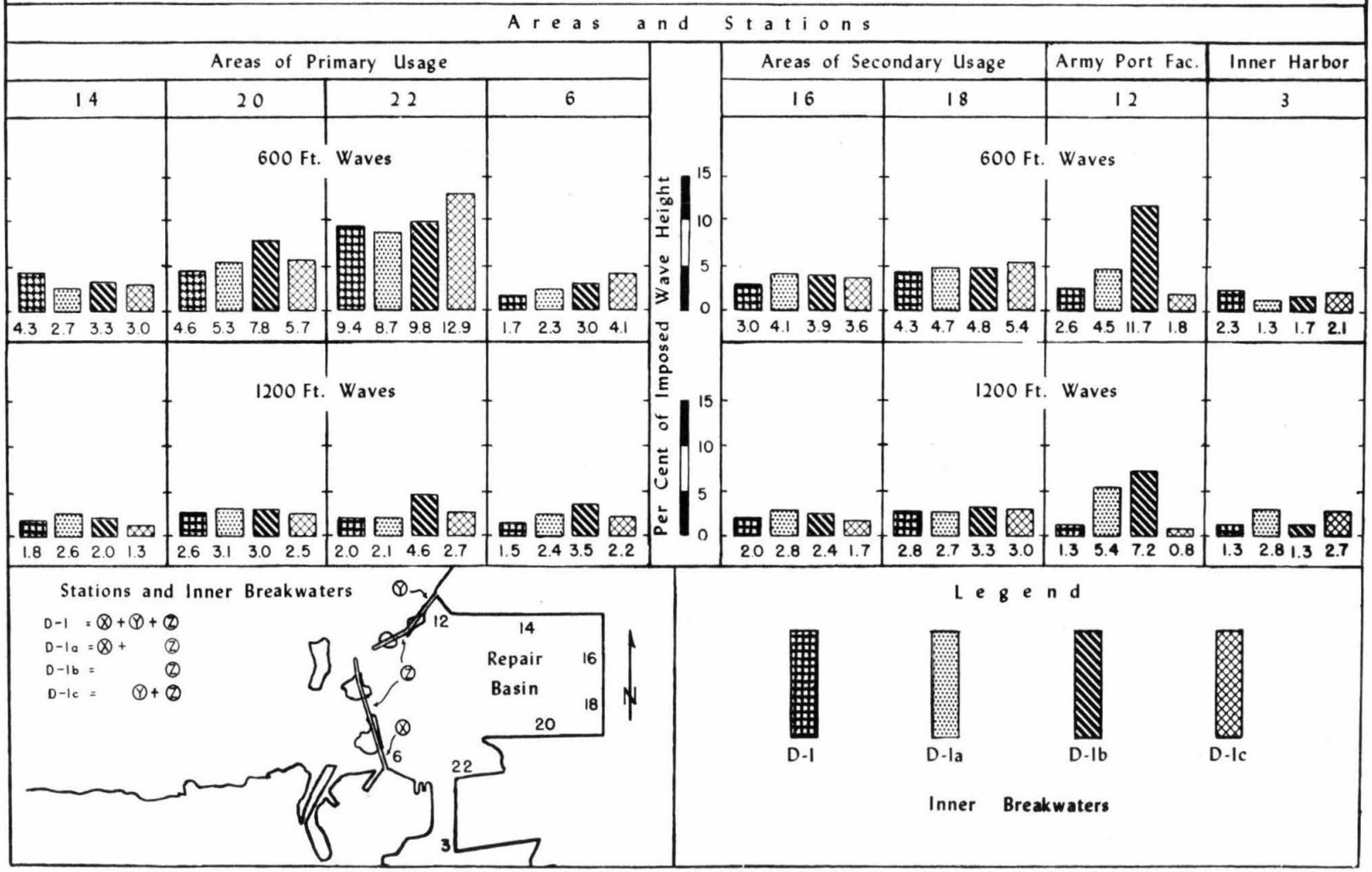


Plate 3

COMPARATIVE EFFECTS OF
MODIFICATIONS OF BREAKWATER D-2

AS MEASURED BY MAXIMUM DISTURBANCES IN REPAIR BASIN AND VICINITY

30 FEET HIGH **WESTERLY** WAVES AT MHHW

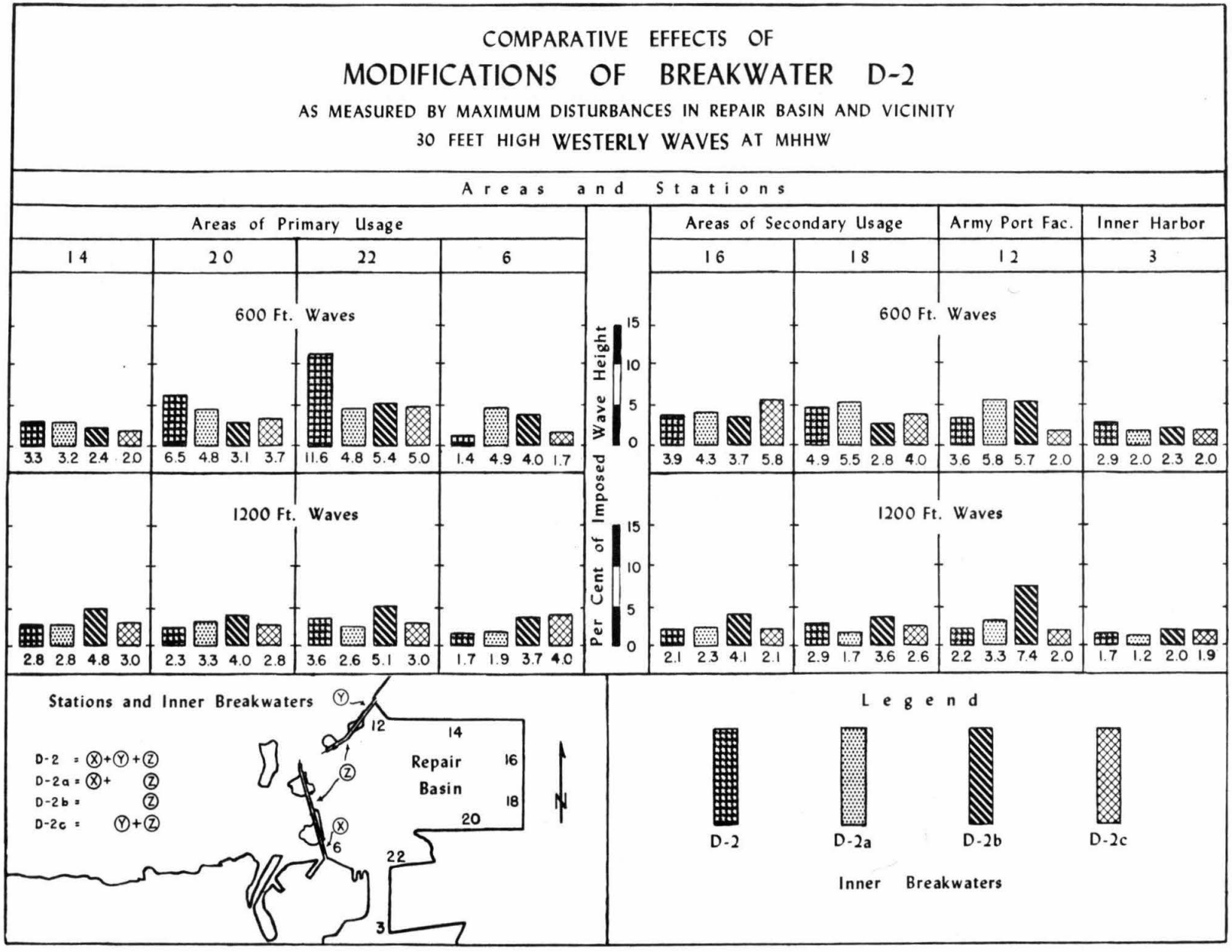


Plate 4

Conclusions

a. For the areas of primary usage in the repair basin any of the inner harbor breakwater structures will reduce by approximately one half the amount of the disturbances which would be present with only the shoals as they now exist for protection. Breakwaters with the North and South Channels filled are more effective than with the channels open. Breakwaters having either the North or South Channel open, but not both, are more effective than those having both channels open. The breakwater segment on Western Shoal adds nothing to the effectiveness of Western Shoal. The breakwater with the sheet piling at the ends, even though it has a narrower opening parallel to the incoming wave front, is slightly less effective than that without sheet piling. At the I-J Docks (Station 22), directly in the path of waves entering the repair basin through the channel between Jade and Southern Shoals, the disturbances with waves 600 feet long are 1½ to 2 times as great with inner breakwaters as with the shoals alone, probably because of the lack of interference pattern present to damp out the waves with the breakwater in place. In the case of waves 1200 feet long the disturbances are about 1/4 to 1/3 as great with inner breakwaters as with the shoals alone.

b. For the area of secondary usage, i.e. the area along the east shore of the repair basin, any of the inner breakwater structures reduce the disturbances to about 40% of those present with only the shoals for protection. All breakwaters offer about the same amount of protection, with breakwater D-1 (rock entirely) giving slightly better protection than the others. Closing both the North and South Channels is better than closing either one only, which in turn is better than leaving both channels open. Again, the breakwater segment on Western Shoal is not effective.

c. At the southwest tip of Army Port Facilities (Station 12) breakwaters having the North Channel closed generally reduce disturbances to about one fifth of those with shoals alone. With the North Channel open the disturbances are only somewhat reduced by breakwaters. Readings at this station have always been erratic and this station is therefore not considered a suitable guide.

d. It should be remembered that the protection afforded by the shoals alone reduces the wave height in the areas of primary usage in the repair basin to about 8% of that of the imposed wave. Thus for a storm wave of 30 feet height, $2\frac{1}{2}$ feet waves would be anticipated in the repair basin with Jade, Southern and Western Shoals alone, as compared to $1\frac{1}{4}$ feet waves with the shoals plus the inner breakwaters.

e. Summary

The addition of a breakwater on Jade and Southern Shoals and the filling of the channels between each of the Jade and each of the Southern Shoals will reduce the disturbances to about half of those present with the shoals alone for protection. Closing of either the North or South Channel, i.e. the channel between Jade Shoals and Army Port Facilities or the channel between Southern Shoals and the south shore of the harbor, will reduce the disturbances an additional amount. Closing of both the North and South Channels reduces the disturbances even more. The breakwater constructed of rock alone is slightly more effective than that supplemented with sheet piling. Since Western Shoal is equally effective with or without a breakwater on top, this portion of the breakwater is unnecessary.

IV HARBOR ENTRANCE COMPARISON STUDY

Discussion

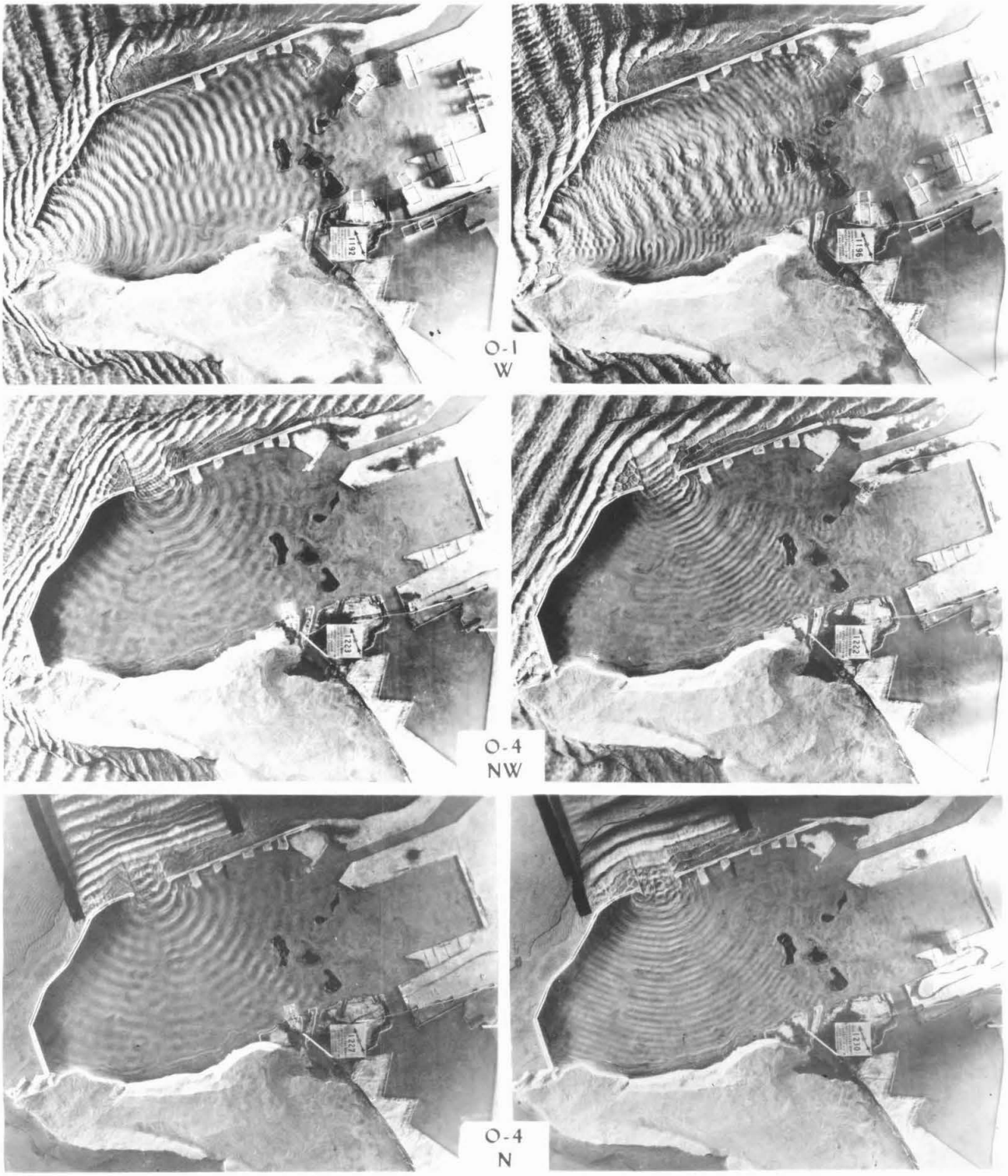
Because of the favorable performance of the entrance through Luminao Reef (0-4) as shown by the photographs, charts, and graphs in last month's report, further studies were made of this entrance to determine its effectiveness in the outer harbor. Plate 5 is a reproduction of the photograph presented last month to show the apparent quieting effect of opening 0-4 when compared with the existing entrance. Four wave height measuring stations (#25 through #28) were selected to represent typical areas in the outer harbor. Their locations may be seen in the lower left corner of Plates 6 through 10.

The data obtained from the wave height measuring stations in the repair basin and inner harbor, representing areas of primary and secondary usage in the repair basin, were presented in last month's report. This presentation has been modified and is included this month to make the alternate opening study complete within itself.

Wave height measurements were made at all twelve stations with waves 30 feet high, 600 and 1200 feet long from the west, from the northwest, and from the north at MHHW for the entrance through Luminao Reef, (Entrance 0-4). For the existing entrance (Entrance 0-1), the same ocean conditions were used with the exception of the omission of northerly waves which were considered relatively unimportant because only waves refracted around the breakwater terminus or reflected from Orote Pt. can enter the harbor, there being no component of the harbor entrance parallel to the wave front.

PLATE 5

These photographs (which are reproduced from last month's report) show the effectiveness of the harbor entrance (O-4) through Luminao Reef. The fronts of the westerly waves in the top pair and the fronts of the northerly waves in the bottom pair of photographs are each parallel to the axis of the opening, permitting the worst wave disturbances. Quantitative measurements were made this month to determine the magnitude of the disturbances in each case.



Waves 30 ft. high, 600 ft. long MHHW Waves 30 ft. high, 1200 ft. long

Comparison of Harbor Entrance O-1 with O-4

Maximum Wave Disturbances

O-1 with Westerly Waves and O-4 with Northerly and Northwesterly Waves

Plate 5

The quantitative comparison of the maximum wave disturbances with these two harbor entrances for the various ocean conditions considered will be found in Tables 2 and 3 and on Plates 6 thru 13 from which the basic data of Tables 2 and 3 were obtained.

Tables 2 and 3 show that northwesterly waves entering the existing entrance (0-1) cause disturbances of the following magnitudes as ratios of the magnitude of the disturbance caused by westerly waves:

1. One half in the outer harbor,
2. One third in the repair basin,
3. One third along the east shore of the repair basin, and
4. One half at the southwest end of Army Port Facilities.

Northerly waves through the reef entrance (0-4) cause disturbances of the following magnitudes as ratios of the magnitude of the disturbance caused by westerly waves through the existing entrance.

1. One fourth in the outer harbor,
2. One half in the repair basin,
3. Two thirds along the east shore of the repair basin, and
4. One half at the southwest end of Army Port Facilities.

Westerly and northwesterly waves through the reef entrance cause disturbances of the following magnitudes as ratios of the magnitude of the disturbance caused by westerly waves through the existing entrance.

1. One fifth and one sixth in the outer harbor,
2. One fifth and one third in the repair basin,
3. One fifth and one third along the east shore of the repair basin, and
4. One-fifth and one third at the southwest end of Army Port Facilities.

On Plates 6 and 10 is shown a comparison of northerly waves through the reef entrance with westerly waves through the existing entrance. The difference is especially striking in the outer harbor.

Westerly waves through the two entrances are compared on Plates 7 and 11. Here again the advantages of the reef entrance are particularly striking. On Plates 8 and 12 is shown a comparison of the effectiveness of entrance O-1 with O-4 both with northwesterly waves. Considering the numerical average of the four outer harbor stations, the reef entrance permits disturbances only half as great in the outer harbor as those allowed by the existing entrance. However, if station #26 near Orote Point is excluded from this average, the disturbances in the outer harbor for waves 600 feet long are not radically different for the two openings. In the other usage areas the reef entrance permits disturbances only one third as large as those allowed by the existing entrance.

A comparison of westerly, northwesterly and northerly waves through the reef entrance is seen on Plates 9 and 13. As would be expected northerly waves produce greater disturbances than waves from other directions. An apparent discrepancy exists in these two plates in that northwesterly waves cause smaller disturbances than westerly waves in the outer harbor but larger disturbances in the other usage areas protected by the reefs.

TABLE 2

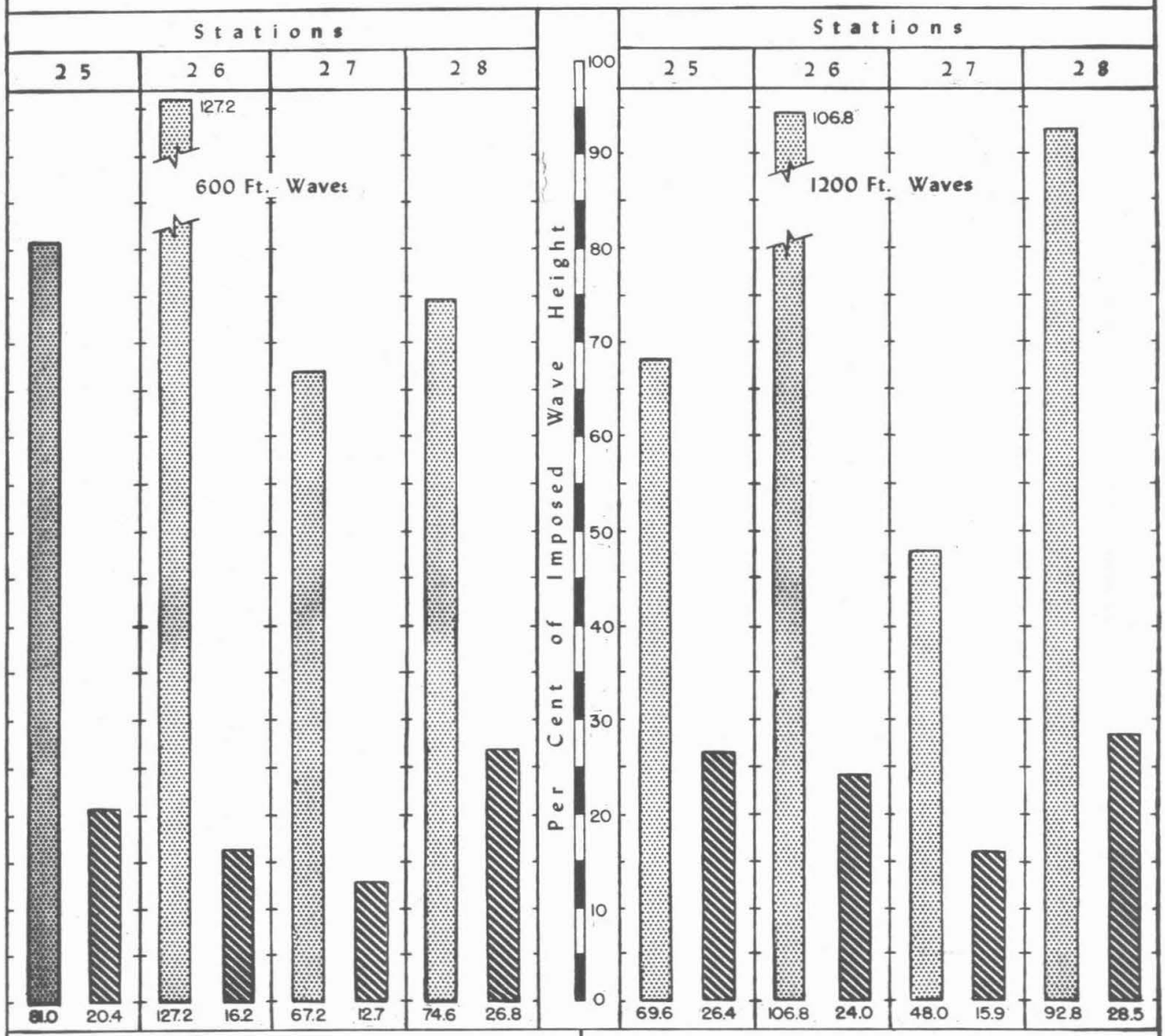
Comparison of Effectiveness of
OUTER HARBOR ENTRANCES 0-1 AND 0-4
as measured by
MAX. WAVE DISTURBANCES AT FOUR STATIONS IN THE OUTER HARBOR
with
Waves 30 feet High, 600 and 1200 feet Long, at MHHW

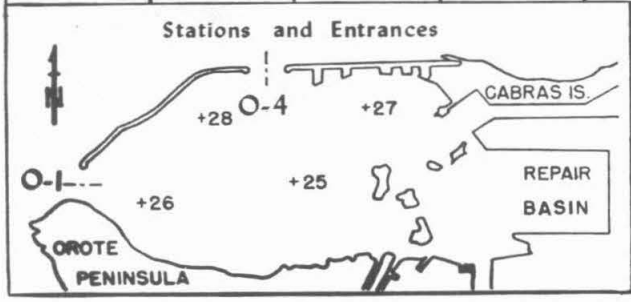
Entrance	Wave Direction	Maximum Disturbances in Percent of Imposed Wave Height			Disturbance Compared to That Occurring With 0-1 Entrance With Westerly Waves (in percent)
		600 ft. long waves	1200 ft. long waves	Ave.	
0-1	W	87.5	79.3	83.4	100
	NW	30.3	49.2	39.7	48
	N	19.0	23.7	21.3	26
0-4	W	15.5	18.3	16.9	20
	NW	13.6	14.5	14.1	17

COMPARATIVE EFFECTIVENESS OF
OUTER HARBOR ENTRANCES O-1 AND O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN OUTER HARBOR

WAVES 30 FEET HIGH, WESTERLY THROUGH O-1, NORTHERLY THROUGH O-4 AT MHHW





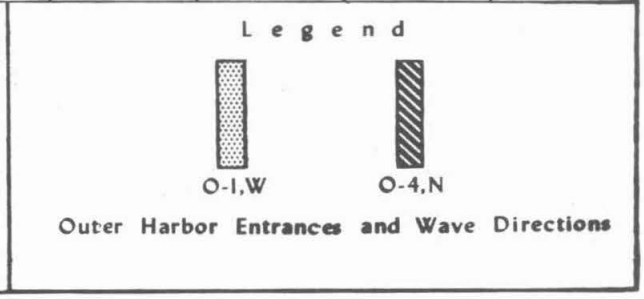


Plate 6

COMPARATIVE EFFECTIVENESS OF
OUTER HARBOR ENTRANCES O-1 AND O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN OUTER HARBOR
30 FEET HIGH WESTERLY WAVES AT MHHW

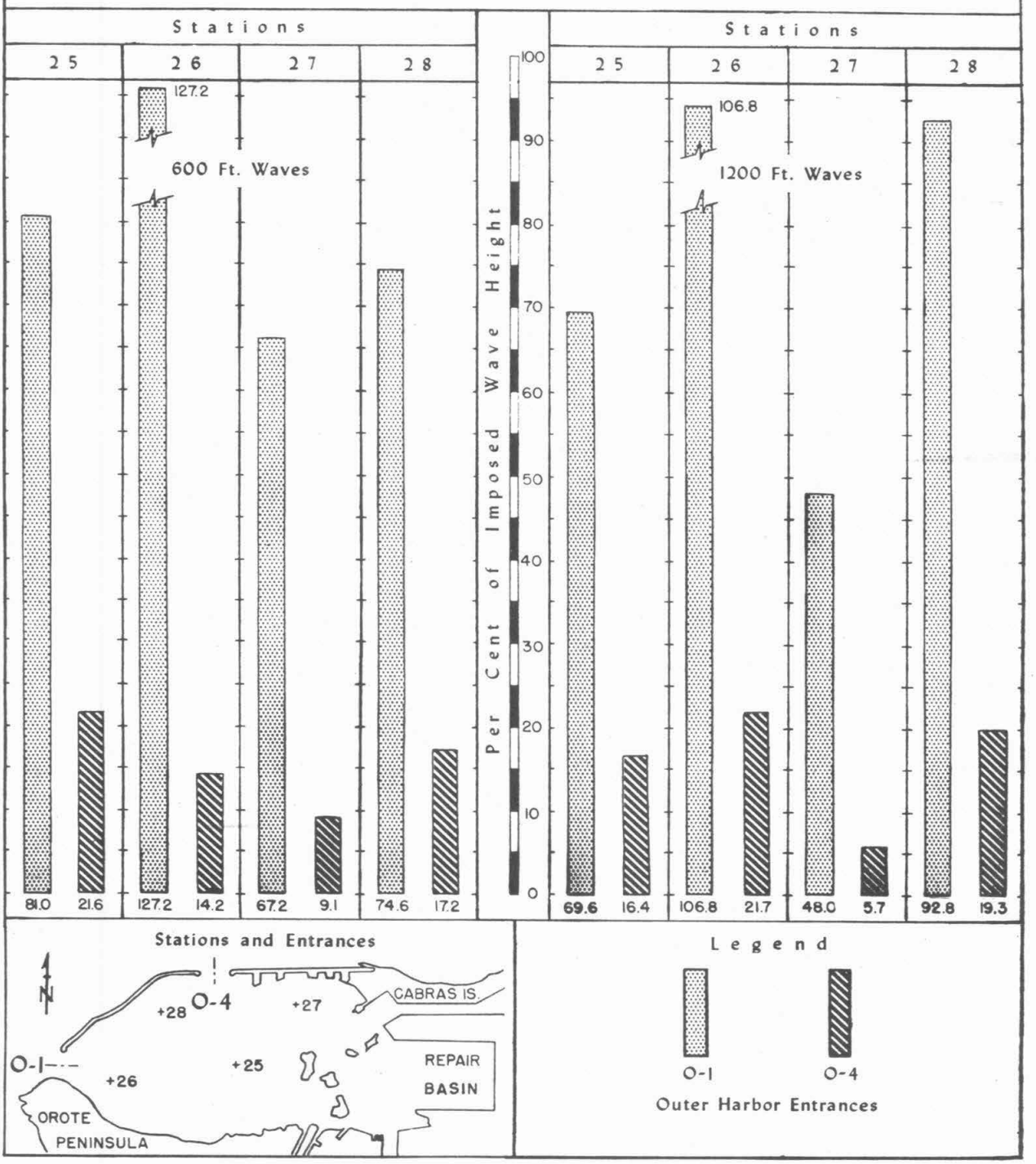
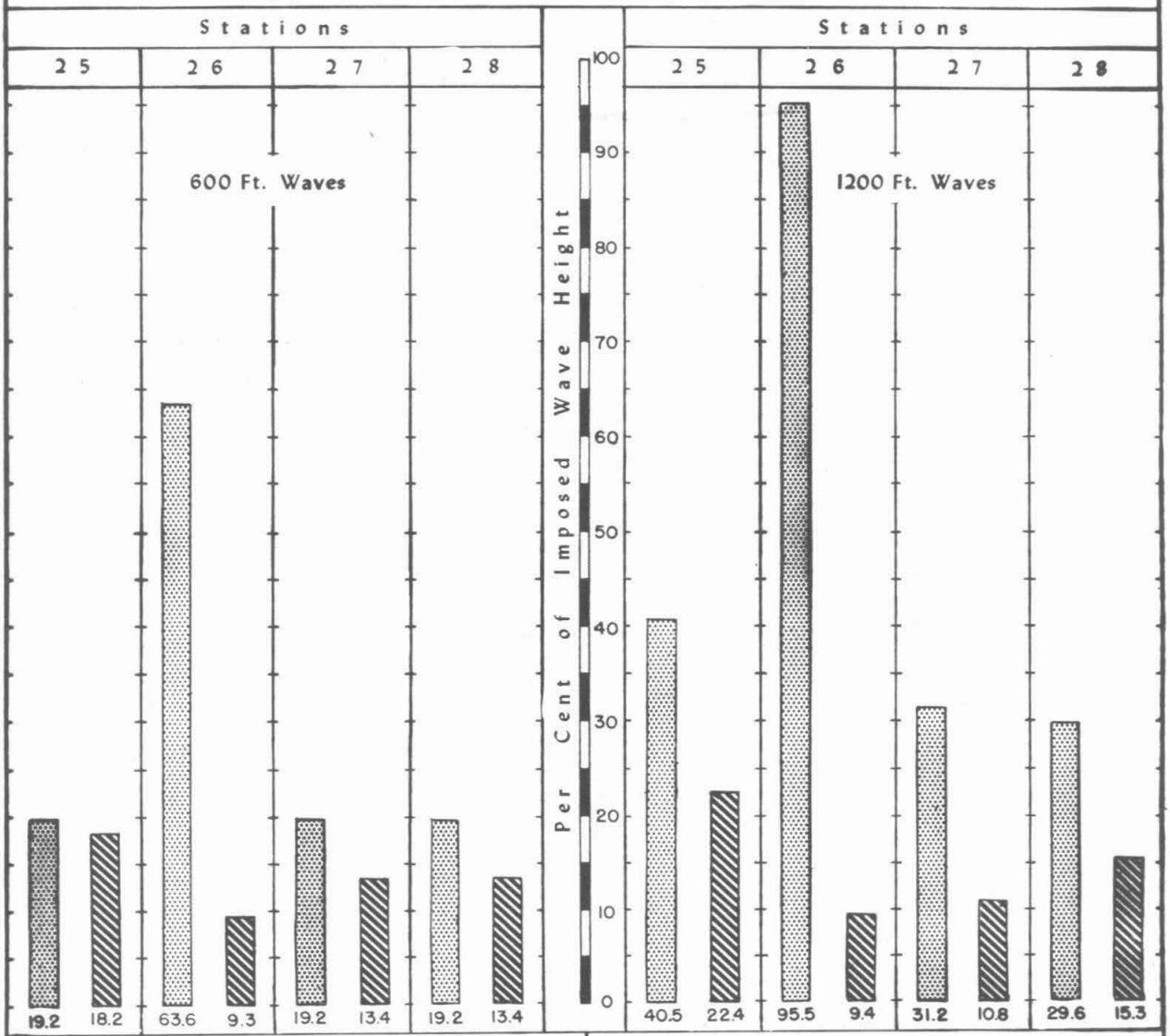
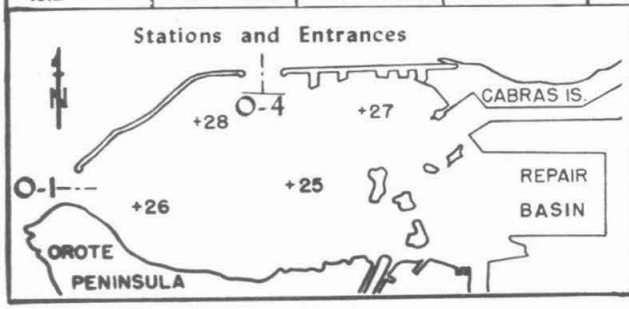


Plate 7

COMPARATIVE EFFECTIVENESS OF
OUTER HARBOR ENTRANCES O-1 AND O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN OUTER HARBOR
30 FEET HIGH NORTHWESTERLY WAVES AT MHHW





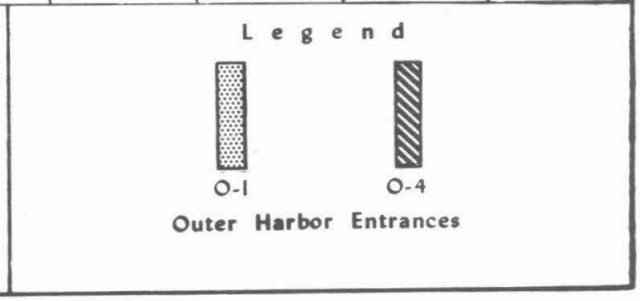


Plate 8

Plate 9

EFFECTS OF WAVE DIRECTIONS THROUGH
OUTER HARBOR ENTRANCE O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN OUTER HARBOR
WAVES 30 FEET HIGH AT MHHW

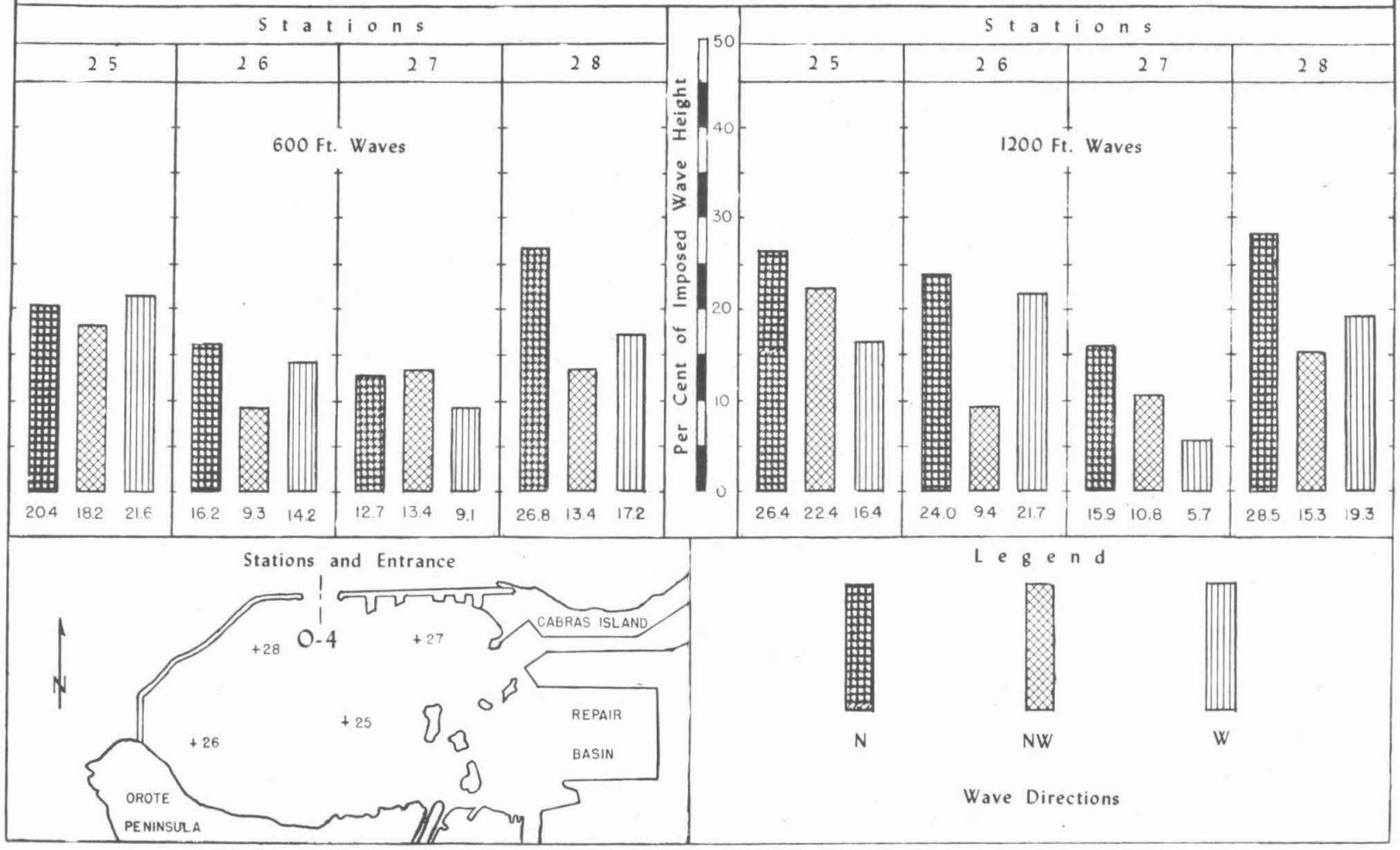


TABLE 3

Comparison of Effectiveness of
OUTER HARBOR ENTRANCES 0-1 AND 0-4
as measured by
MAXIMUM WAVE DISTURBANCES IN THREE AREAS
protected by Jade, Southern, and Western Shoals
with waves 30 feet high and 600 and 1200 feet long at MHHW

Entrance and Wave Direction	Wave Length, Feet	Areas of Primary Usage in the Repair Basin			Areas of Secondary Usage in the Repair Basin			Southwest End of Army Port Facilities		
		Maximum Disturbance Percent of Imposed Wave Height		Disturbance Compared With 0-1,W (percent)	Maximum Disturbance Percent of Imposed Wave Height		Disturbance Compared With 0-1,W (percent)	Maximum Disturbance Percent of Imposed Wave Height		Disturbance Compared With 0-1,W (percent)
		Each Wave Length	Ave. 600' and 1200'		Each Wave Length	Ave. 600' and 1200'		Each Wave Length	Ave. 600' and 1200'	
0-1 W	600	5.40	7.79	100	7.60	8.10	100	10.30	12.25	100
	1200	10.18			8.60			14.20		
0-1 NW	600	2.38	3.15	40	2.50	2.82	35	7.10	6.30	51
	1200	3.92			3.15			5.50		
0-4 N	600	3.30	4.54	58	3.15	4.88	60	5.40	5.40	44
	1200	5.78			6.60			5.40		
0-4 W	600	1.25	1.45	19	1.10	1.45	18	2.20	2.20	18
	1200	1.65			1.80			2.20		
0-4 NW	600	2.10	2.74	35	2.10	3.08	38	3.60	4.20	34
	1200	3.38			4.05			4.80		

COMPARATIVE EFFECTIVENESS OF
OUTER HARBOR ENTRANCES O-1 AND O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN REPAIR BASIN AND VICINITY

WAVES 30 FEET HIGH WESTERLY THROUGH O-1, NORTHERLY THROUGH O-4 AT MHHW

JADE, SOUTHERN, AND WESTERN SHOALS IN PLACE

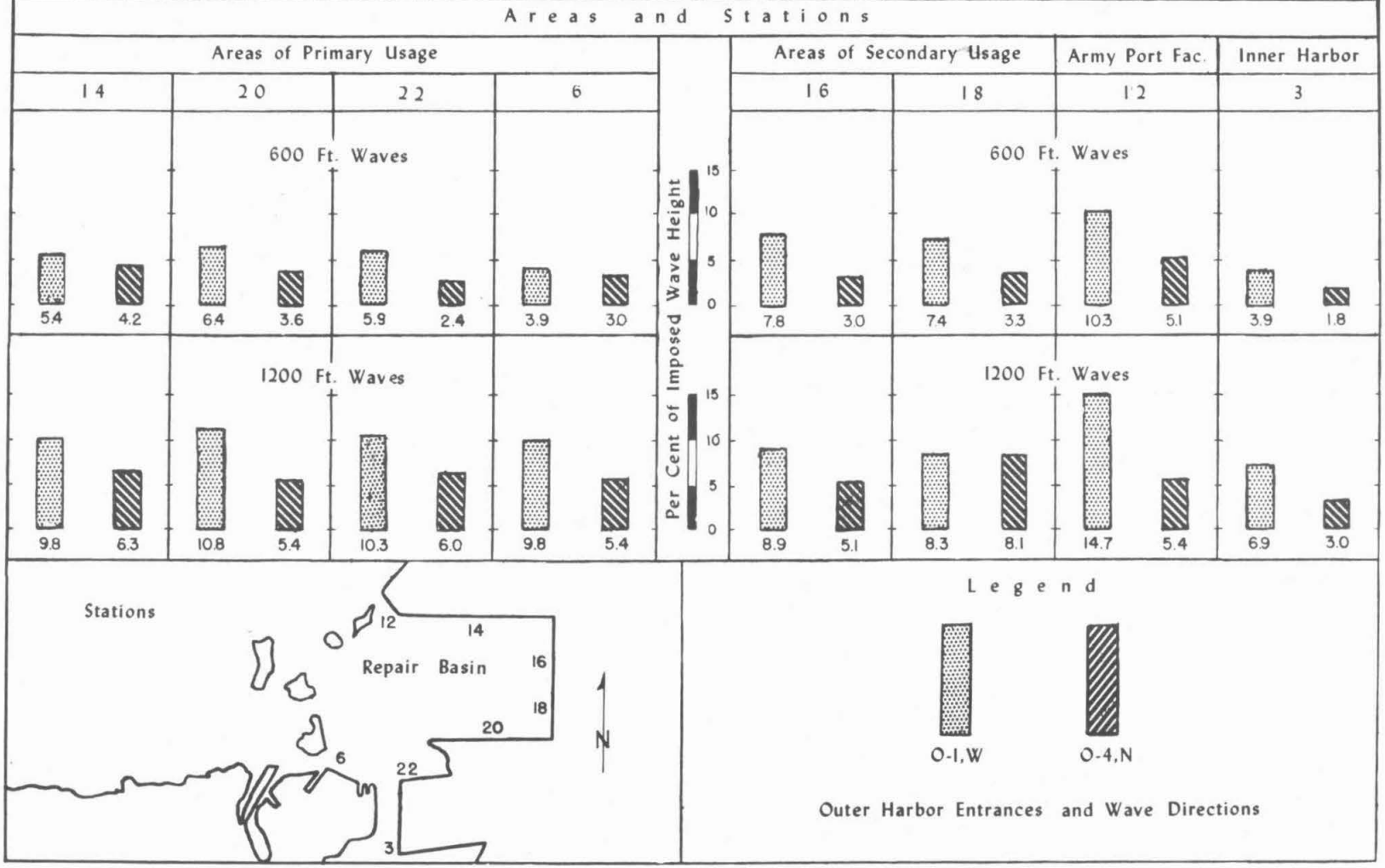


Plate 10

COMPARATIVE EFFECTIVENESS OF
OUTER HARBOR ENTRANCES O-I AND O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN REPAIR BASIN AND VICINITY

30 FEET HIGH WESTERLY WAVES AT MHHW

JADE, SOUTHERN WESTERN SHOALS IN PLACE

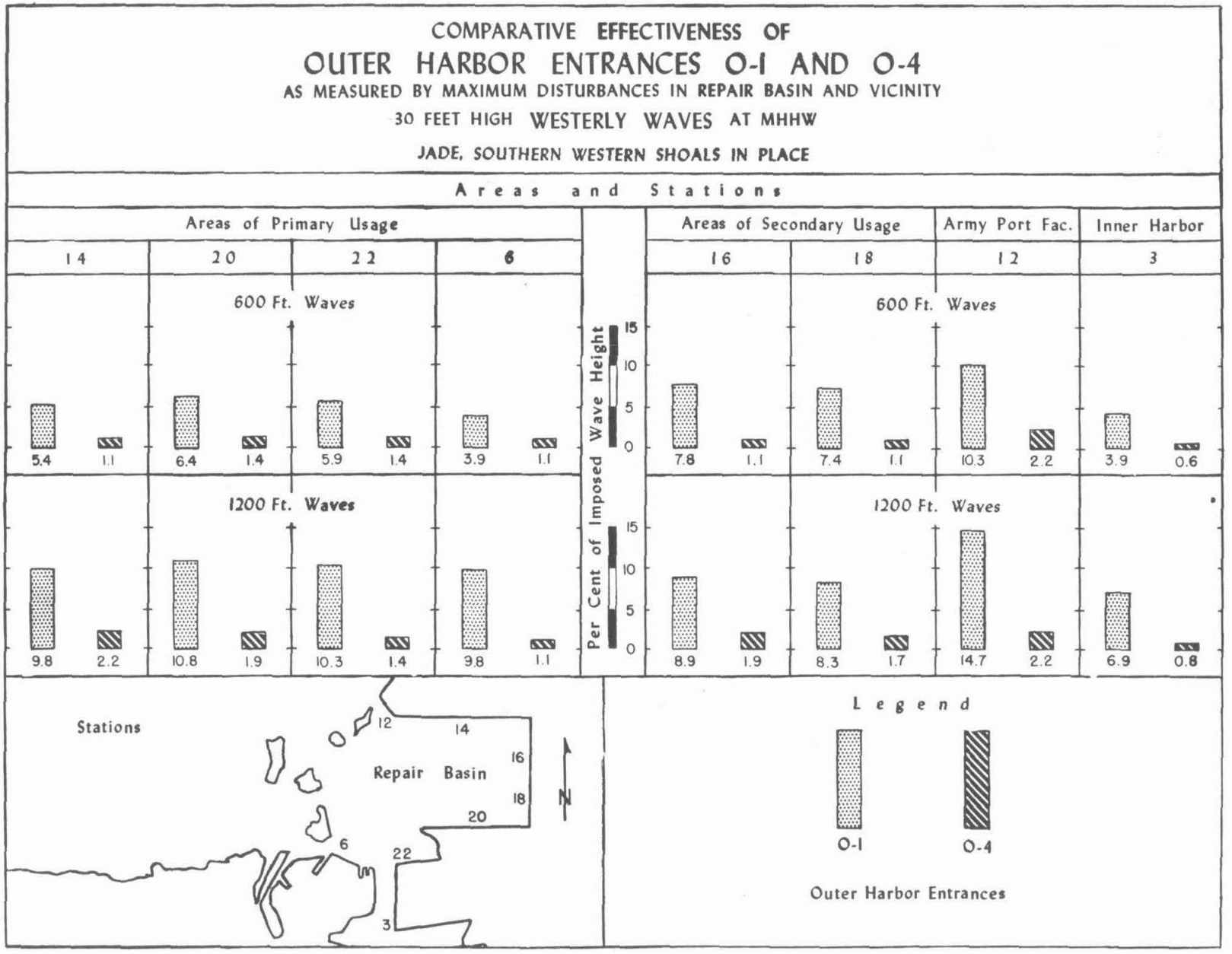


Plate 11

COMPARATIVE EFFECTIVENESS OF

OUTER HARBOR ENTRANCES O-1 AND O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN REPAIR BASIN AND VICINITY

30 FEET HIGH NORTHWESTERLY WAVES AT MHHW

JADE, SOUTHERN AND WESTERN SHOALS IN PLACE

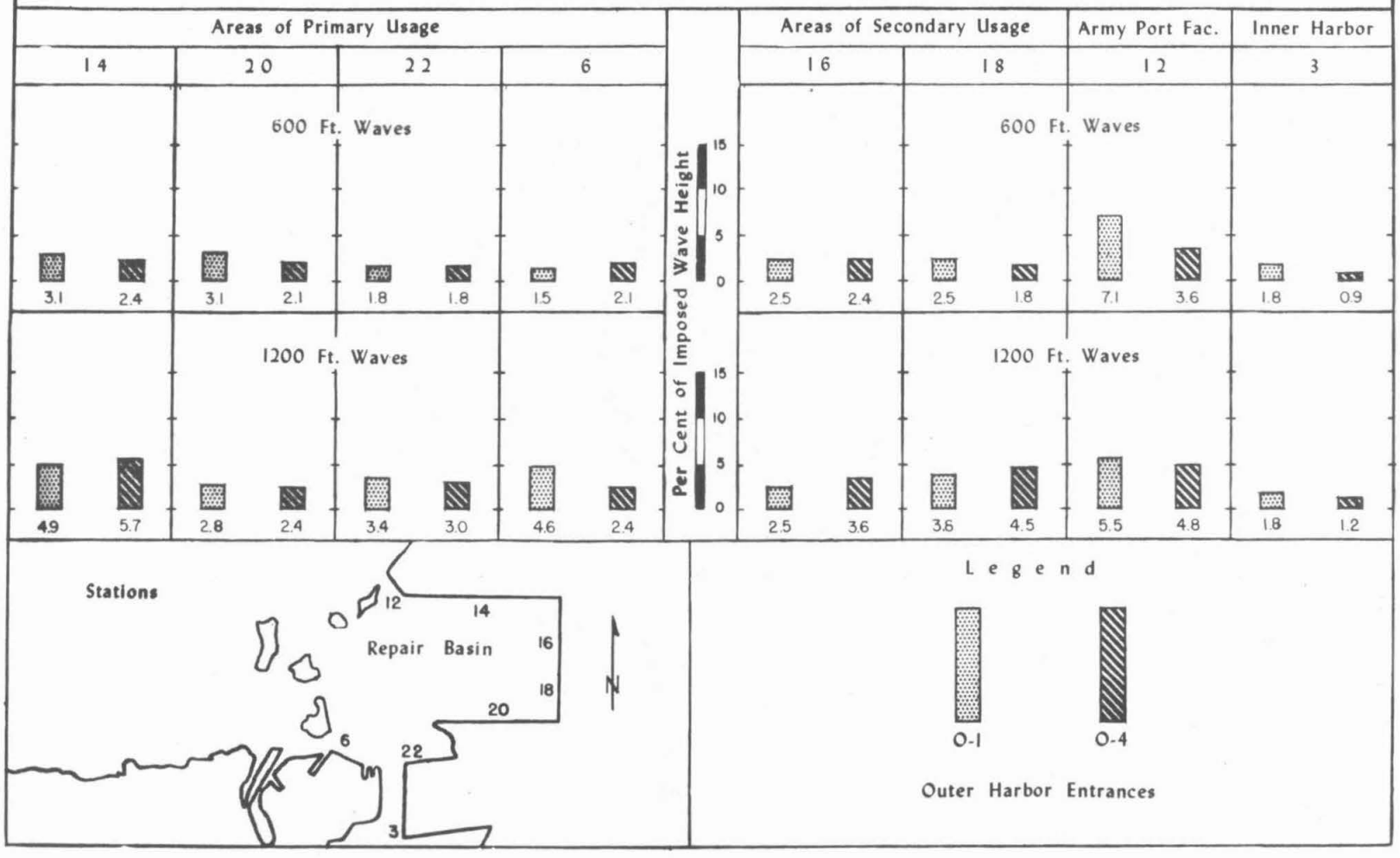
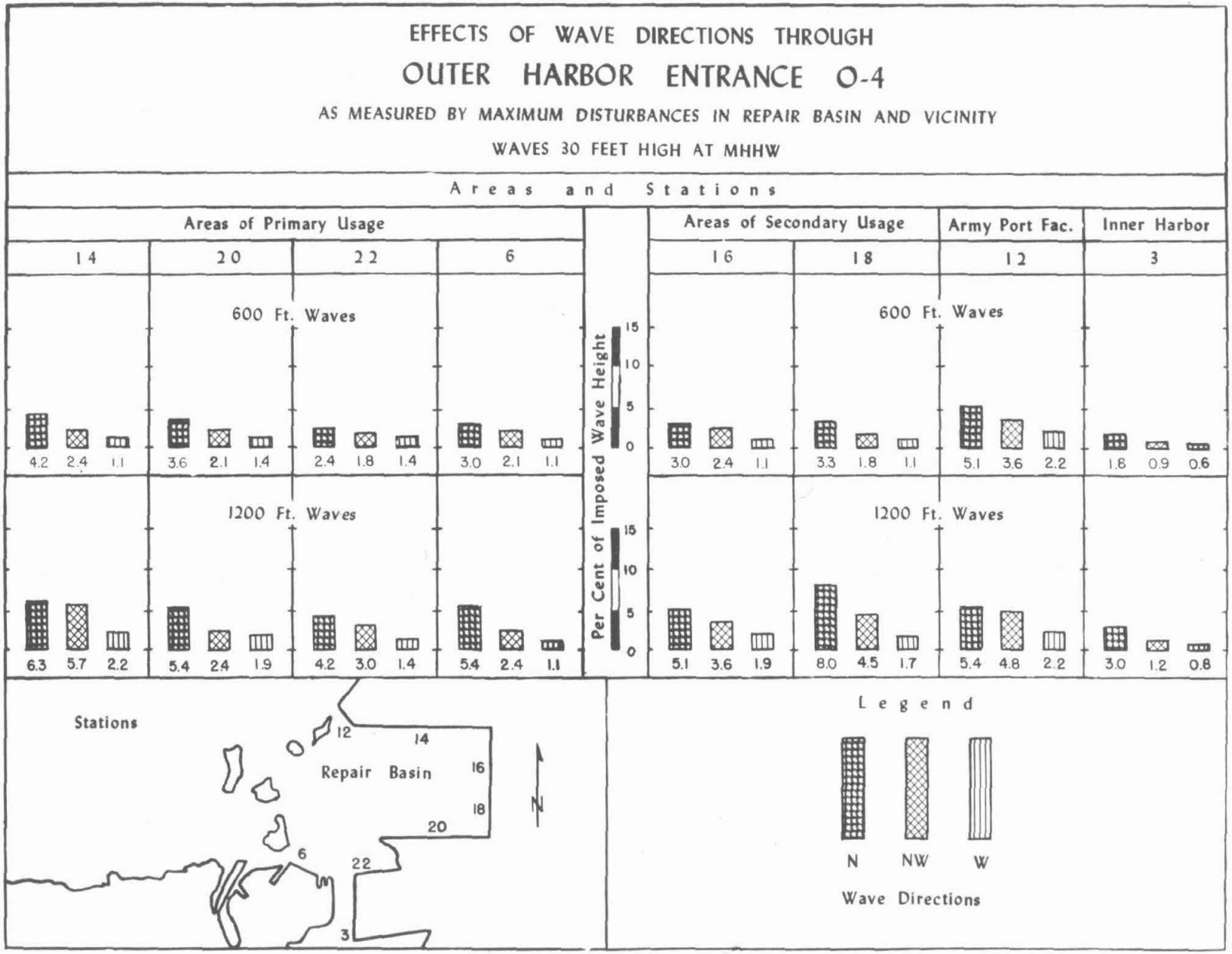


Plate 12

EFFECTS OF WAVE DIRECTIONS THROUGH
OUTER HARBOR ENTRANCE O-4

AS MEASURED BY MAXIMUM DISTURBANCES IN REPAIR BASIN AND VICINITY

WAVES 30 FEET HIGH AT MHHW



Conclusions

The conclusions to be drawn from the results of the studies of an alternate entrance through Luminao Reef may now be summarized. The terms worst, most intense and most frequent when referring to wave directions are indicative, respectively, of northerly waves through 0-4 and westerly through 0-1, westerly waves through both entrances, and northwesterly waves through both entrances.

a) In the outer harbor, the disturbances permitted by the alternate entrance (0-4) under the worst wave direction, (northerly waves) are reduced to one-fourth those present with the existing entrance (0-1) under the worst wave direction (westerly waves). During the visit of the Institute representatives to Guam in February 1946, Comdr. Franklin, then in charge of Fleet Weather Central at Guam, gave definite evidence that the most intense storm waves come from the west and that the most frequent storm waves come from the northwest. For westerly waves the Luminao Reef entrance admits disturbances only one fifth the magnitude of those with the existing entrance. For northwesterly waves the Luminao Reef entrance reduces disturbances to 35% of those with the existing entrance.

b) In areas of primary usage in the repair basin the disturbances with the Luminao Reef entrance are approximately half those with the existing entrance under the worst storm wave directions, i.e. northerly waves thru the reef entrance, westerly waves thru the existing entrance. Through the reef entrance, westerly waves, the most intense, cause disturbances only 18% of those with the existing entrance.

Northwesterly waves, the most frequent, cause disturbances of approximately the same magnitude with either entrance.

c) In the areas of secondary usage along the east shore of the repair basin the reduction in disturbances with the reef entrance are approximately the same under all wave directions as in the areas of primary usage.

d) Protection of the southwest end of Army Port Facilities (Station 12) is also best afforded by the reef entrance. Here the disturbances, with the worst wave directions are reduced to less than half, under the most severe to 18% and most frequent to two thirds.

e) At the entrance to the inner harbor the disturbances are reduced to less than half under the worst wave directions, to approximately one eighth under the most intense direction and to less than two thirds under the most frequent storm wave direction.

f) Summary

The entrance through Luminao Reef appears to have good possibilities. Not only are disturbances throughout the areas of primary and secondary usage reduced by one half or more, but the disturbances in the outer harbor are reduced by great amounts, i.e., to one fourth under the worst storm wave directions, to one fifth under the most intense storm wave direction and to one third under the most frequent storm wave direction. These drastic reductions cannot be emphasized too strongly in the light of the great possibilities they hold for more extensive use of the outer harbor.

V COMPARISON OF POSSIBLE PROTECTIVE MEASURES FOR REPAIR BASIN AND INNER HARBOR

Discussion

Several means of protecting the repair basin and inner harbor have been studied in great detail during the past months. These are

1. shoals as they presently exist
2. filling in various channels between the shoals
3. breakwaters on the shoals
4. closing the existing entrance, cutting a new one through Luminao Reef and utilizing the existing shoals.

Little need be said about the shoals as they presently exist except that test runs summarized in past reports have shown that the shoals do a great deal of good by themselves in protecting the repair basin and inner harbor. By the proper combinations of channel fills and shoals the effectiveness of the shoals can be increased as much as 25%, as shown by the April report.

The construction of breakwaters on the shoals, Section III of this report, was found to increase the protection offered the repair basin and inner harbor even more. Only breakwaters considered economically feasible were studied. If an inner breakwater could be extended into deeper water, further protection would be gained because of the narrowing of the opening parallel to the wave front.

Closing the existing entrance and cutting a new one through Luminao Reef offers possibilities for even greater protection. Only the shoals as they presently exist were considered in the studies conducted so far. Undoubtedly, the filling of various of the channels between the shoals

would further improve the performance of the reef entrance.

Table 4 presents a comparative summary of the protection afforded the repair basin and the east shore of the repair basin by the shoals alone, by the two best combinations of shoals and channel fills, by the two best breakwaters and by the new entrance with the shoals alone.

TABLE 4

Comparative Effectiveness of
Various Protective Measures Applied
To the OUTER HARBOR and REPAIR BASIN

Entrance and Wave Direction	Protection	Wave Length, Feet	Areas of Primary Usage in the Repair Basin			Areas of Secondary Usage in the Repair Basin		
			Maximum Disturbance Percent of Imposed Wave Height		Disturbance Compared to that Occurring with O-1W and Shoals JSW (percent)	Maximum Disturbance Percent of Imposed Wave Height		Disturbance Compared to that Occurring with O-1W and Shoals JSW (percent)
			Each Wave Length	Ave. 600' and 1200'		Each Wave Length	Ave. 600' and 1200'	
O-1,W	* JSW	600	5.4	7.8	100	7.6	8.4	100
		1200	10.2			9.1		
O-1,W	* JSW Mod.	600	4.9	6.4	82	6.4	7.5	89
		1200	8.0			8.6		
O-1,W	*JSW Mod. and Cl.No.Ch.	600	6.6	6.1	78	7.1	7.2	86
		1200	5.6			7.4		
O-1,W	E-1	600	4.7	3.5	45	3.7	3.2	38
		1200	2.3			2.8		
O-1,W	D-1	600	5.0	3.5	45	3.7	3.1	37
		1200	2.0			2.4		
O-4,W	JSW	600	1.2	1.4	18	1.1	1.4	17
		1200	1.6			1.8		
O-4,N	* JSW	600	3.3	4.6	59	3.2	4.9	58
		1200	5.8			6.6		

*JSW = Jade, Southern and Western Shoals in place
Mod = Channels between the two Jade and the two Southern Shoals filled
Cl. No. Ch. = Channel between Jade Shoals and Army Port Facilities filled

Summary of Conclusions

Jade, Southern and Western Shoals are of great importance in reducing the disturbances which enter the repair basin and inner harbor. Their usefulness can be improved somewhat:

1. by filling the channel between each of the two Jade and each of the two Southern Shoals
2. by filling the channel between Army Port Facilities and Jade Shoals in addition to fills described in paragraph (1) above.

The first of these modifications will reduce the disturbances to about 85% and the second to about 80% of those permitted by the shoals alone. Breakwaters on the shoals will reduce the disturbances to about 40% of those permitted by the shoals alone, or to approximately half those permitted by the shoals plus the channel fills.

The reef entrance (0-4) with no modification to the shoals reduces the disturbances in the repair basin and along the east shore of the repair basin to about 60% of the disturbances permitted by the shoals alone with the present entrance during periods of the worst storm wave directions (northerly through 0-4, westerly through 0-1), and to about 18% of the disturbances permitted by the shoals alone with the present entrance during periods of most intense storm waves (westerly). This means that for the most intense wave direction, by changing the entrance alone and leaving the shoals as they exist, the repair basin, and inner harbor would have better protection than they would have if the complete inner breakwater were built with the present entrance in use. Furthermore, by changing the entrance the entire outer harbor is quieted to the extent that disturbances of only about one-fourth the

present magnitude would exist. There is no apparent way of achieving this desirable result with the present entrance.